Carob Fiber Benefits and Applications

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Dietary fibers are a heterogeneous group of food components. They are characterized by resistance to digestion and absorption in the human small intestine, as well as complete or partial fermentation in the large intestine (2). This definition not only encompasses traditional dietary fiber components, such as nonstarch polysaccharides (cellulose, hemicelluloses) and lignin, but also oligosaccharides, resistant starches, and associated plant substances.

Carob fiber is an insoluble dietary fiber obtained from the deseeded husk of the carob fruit. Carob fiber also contains significant amounts of both insoluble and water-soluble polyphenols, which sets it apart from other traditional sources of insoluble dietary fiber, such as wheat bran, cellulose, and soy fiber. Spain, the largest producer of carob, is responsible for more than 40% of the carob production worldwide, followed by Italy and Portugal (5). Although native to the Mediterranean Region, the carob tree is also found in the United States (e.g., Arizona and California) and some parts of Central and South America.

Historic Use of Carob

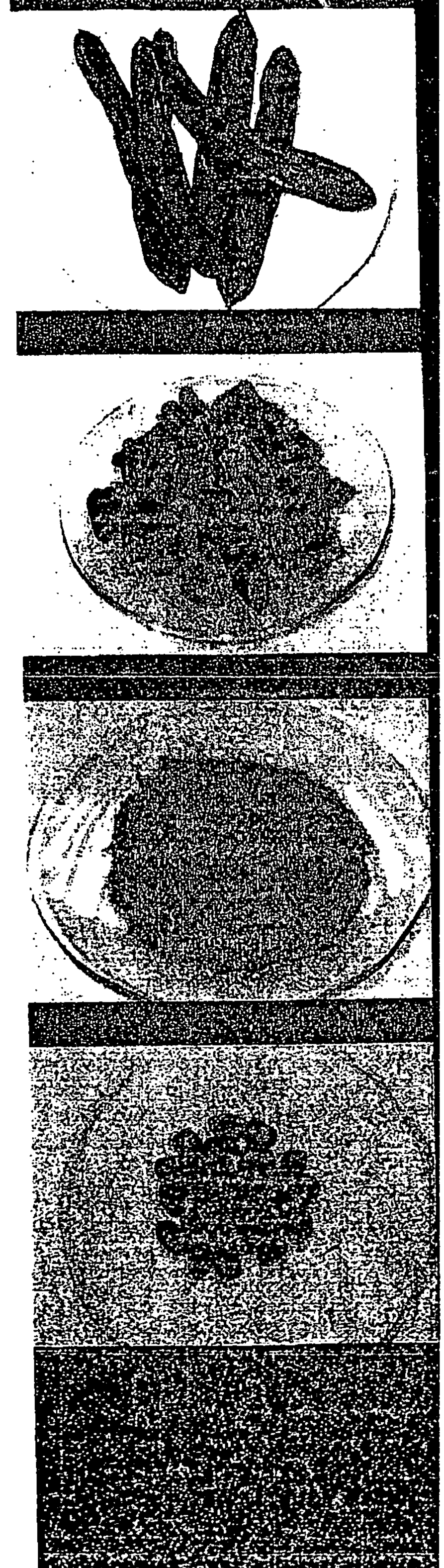
The brown carob pod, also known as St. John's bread or locust bean, is a carbohydrate-rich fruit that has been used as a source of nutrition for centuries. The biblical story of John the Baptist, who survived in the desert by eating locust and wild honey, is possibly one of the earliest references to human carob consumption. During hard times, the edible pods have been directly consumed as food. It is reported, for example, that the cavalries of British generals Wellington in Spain and Allenby in Palestine ate edible carob pods (26) during World War I. Since then, owing to its pleasant sweet taste, carob has most often been used as an inexpensive candy for children.

Carob was introduced into Mexico and southern California by Spanish missionaries. In 1854, 8,000 seedlings from Spanish seeds were distributed by the U.S. Patent Office throughout the southern United States. In the following years, carob seeds from different countries were imported into the United States (5,19). During the early 1920s and the 1950s, there was intense promotion of carob, including a USDA research program on various applications of the fruit crop, especially in California (9,10,19). At this time, imported carob pods were regularly sold in the United States as inexpensive candy by street vendors, while carob flour was used to produce chocolate substitutes and "health food" products (7,9,22,27).

Today, carob is widely known for the galactomannan found in its seeds. Galactomannan, generally known as locust bean gum (carob bean gum) in the food industry, is known for its strong viscosity-increasing effect. Other carob ingredients include carob syrup and carob powder (roasted and unroasted). Carob applications include cereals, snacks, health bars, carob bars, confectionery and bakery products, carob spreads, cocoa and chocolate alternatives, teas, and infusions. Carob powder is also used as a mild antidiarrheic agent, especially in cases of infantile diarrhea (3,17).

Carob Fiber Composition and Production

Carob fruit weight varies, depending on variety and region, between 5 and 30 g (12–15 g on average). The seeds account for just 10–15% of the whole. Although the overall composition depends on the variety (18,25), the pulp of the carob fruit contains substantial amounts of sugars, normally 40–50%, and approximately 30–40% total



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dietary fiber. Substantial amounts of tannins and polyphenols are also present in the pulp (24), as evidenced when determining total dietary fiber using AACC Approved Method 32-05 (1) or AOAC method 985.29 (4). Other components include proteins, minerals, and inositols, such as pinitol (6).

The production of carob fiber begins with the removal of the seeds, which are processed separately into locust bean gum. Water used to extract the comminuted pods dissolves the vast majority of soluble carbohydrates and yields a product that contains mostly dietary fiber, as well as insoluble tannins, a small amount of low-molecular weight carbohydrates, minerals, and water-soluble polyphenols. The total dietary fiber content, determined according to AACC Approved Method 32-05 (1) or AOAC method 985.29 (4), of the resulting product typically exceeds 75% (based on dry matter), which makes the ingredient suitable for fortifying foods with dietary fiber. The typical composition of carob fiber is shown in Table I.

The insoluble dietary fiber fraction mainly consists of cellulose, hemicelluloses, and lignin, as well as water-insoluble polyphenols. The water-soluble fraction contains simple carbohydrates, like sucrose, glucose, and fructose, and the methyl inositol pinitol. Recent research has shown that a wide variety of water-soluble polyphenols can be obtained from carob fiber, with hydrolysable tannins, a variety of flavonol glycosides, and gallic acid as the main constituents.

Health Benefits of Carob Fiber

Historically, carob fiber has been used for its health-promoting attributes. New research is now focusing more closely on the cholesterol attenuation activity and antioxidative properties of carob fiber.

Cholesterol Attenuation. Two human studies with more than 100 subjects confirmed that carob fiber, as part of a well-balanced diet, can significantly reduce cholesterol levels, especially low-density lipoprotein (LDL) cholesterol, in hypercholesterolemic people. In an open, uncontrolled clinical trial, a daily intake of 15 g of carob fiber reduced total serum cholesterol and LDL cholesterol by 7.8 and 12.1%, respectively, after six weeks (29). Food products containing carob fiber tested in the trial included a breakfast cereal, nutrition bar and powdered drink (one portion each per day). In a second placebo-controlled, randomized clinical trial, two portions of bread and one serving of a nutrition bar were used to administer a daily dose of 15 g of carob fiber. In this study, total cholesterol and LDL cholesterol were reduced by 9.0 and 10.5%, respectively, in the carob fiber group compared with the control group after six weeks. Furthermore, apolipoprotein B was significantly reduced by 11.9% after carob fiber treatment (14). Animal and in vitro trials on carob fiber and its components indicate that carob fiber may increase bile acid excretion while minimally affecting cholesterol absorption (20,21,28).

Viscous fibers from psyllium husk and oat bran have been shown to lower total and LDL cholesterol levels (8,13). Carob fiber shows comparable results, which are not normally seen with an insoluble dietary fiber, but which may be explained by its high lignin and insoluble polyphenol content. According to Brown and coworkers (8), 1 g of soluble fiber from oat or psyllium produced changes in total cholesterol levels of −1.42 and −1.10 mg/dL and in LDL cholesterol levels of −1.23 and −1.11 mg/dL, respectively. Results from the two human studies (14,29) on carob fiber showed a reduction in total cholesterol of −1.44 mg/dL and in LDL cholesterol of −1.33 mg/dL per gram of carob fiber. These results indicate the potential of carob fiber, as part of a balanced diet, to help lower cholesterol levels and reduce the risk for cardiovascular disease.

Antioxidative Properties. Although carob is rich in insoluble polyphenols, especially condensed tannins, water-soluble polyphenols have also been found (18,25). Recently, Kumazawa and coworkers (16) showed that water-soluble carob polyphenols exhibit antioxidative activity in different in vitro models, such as the β-carotene discoloration assay and the DPPH (diphenyl-picrylhydrazyl) radical test. Because carob fiber is the remnant of water-extracted carob pulp, its antioxidative activity should be low. However, carob fiber contains substantial amounts of antioxidants that can scavenge reactive substances, such as free radicals, in vitro (11).

Using the TEAC (Trolox equivalent antioxidative capacity) test (23), a model system that simulates the initial reaction of lipid peroxidation, water extracts of carob fiber had an antioxidative capacity that was greater than that of other fiber sources tested. Although carob fiber extracts contain twice as many total phenols as wheat bran or oat bran (determined by Folin-Ciocalteau's reaction), the TEAC values, standardized to 1 g of total phenols, were much higher for carob fiber compared with those for the other fiber sources tested (Fig. 1).

To test the scavenging activity of antioxidants against reactive oxygen species (ROS), other test systems, including NADH/diaphorase, xanthin oxidase, and HOCl, can be deployed (12,15). Both the NADH/diaphorase and xanthin oxidase test systems are more applicable for determining ability of antioxidants to scavenge physio-

Table I. Typical composition of carob fiber

Component	Amount per 100 g of Fiber
Moisture	Max. 8 g
Total dietary fiber (db)[a]	Min. 75 g
Insoluble dietary fiber	Min. 70 g
Soluble dietary fiber	Max. 10 g
Carbohydrates	Approx. 6 g
Protein	Approx. 5 g
Fat	Approx. 2 g
Energy	Approx. 40–75 kcal

[a] Determined using AACC Approved Method 32-05 (1) (AOAC method 985.29 [4]).

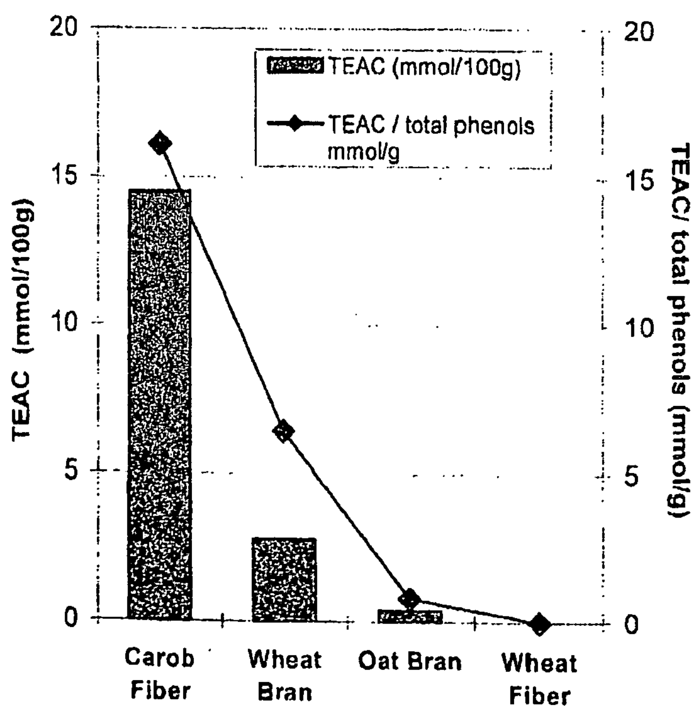

Fig. 1. Capacity of dietary fibers to scavenge $ABTS^{\cdot+}$ (2,2'-azino-bis-[3-ethyl-benzothiazoline-6-sulphonic acid]), expressed as TEAC value and TEAC/total phenol.

logically occurring ROS. Carob fiber showed a very high antioxidative capacity against ROS, even higher than the positive control (Trolox) (Table II). This total activity can be attributed both to the water-soluble components of carob fiber and to the insoluble residue. Interestingly, the calculated sum of the activity of the single fractions was higher than that of the carob fiber itself, which indicates that soluble and insoluble antioxidants interfere with each other within these test systems (Fig. 2). Soluble polyphenols can be absorbed in the intestine, which may enhance their antioxidative capacity in different parts of the human body (e.g., intestinal mucosa or blood serum), while insoluble polyphenols stay primarily in the intestine, where they are able to scavenge reactive components produced from the diet or bacteria.

Carob fiber also exhibits activity against HOCl, which is generated by polymorphonuclear granulocytes and, when excessively produced, can cause tissue damage. Normally, HOCl can be scavenged by reaction with NH_2 groups or addition to double bonds. Anti-inflammatory agents, such as 5-aminosalicylic acid, can be used to reduce symptoms caused by higher levels of HOCl. Of the dietary fibers tested, carob fiber showed the highest activity against HOCl (Table II). Approximately 60% of the reactivity of carob fiber can be attributed to its water-soluble components and approximately 40% can be attributed to its insoluble residue (Fig. 3).

Overall, carob fiber represents a good source of dietary fiber that is high in naturally active antioxidants. Additionally, the results show that its antioxidant capacity is not determined simply by the quantity of polyphenols, but also by the type of polyphenol. In addition to reducing cholesterol levels, this antioxidative activity could help reduce the risk of cardiovascular disease and improve general health.

Adding Carob Fiber to Baked Goods

Fibers perform multiple functions. Much of their functionality comes from their ability to absorb and bind water—a factor that can be dramatically affected by the size of the fiber particle. The shape and chemical composition of the fiber particle also influences its functionality. Water can serve as an economical and noncaloric addition to many products, and in its bound form may increase product shelf life. The best method for adding fiber, however, depends on the application. Carob fiber is suited for use in a variety of applications, including baked goods, health bars, extruded products, dairy drinks, and dietary supplements, and can be used as either a "classic" dietary fiber component or a "functional" ingredient. In products containing fiber from different sources, synergies with other fibers can be achieved.

Table II. IC_{50} values determined for scavenging reactive oxygen species and hypochlorite

Source	IC_{50} Values for Xanthin Oxidase Test (mg/2 mL)	IC_{50} Values for HOCl Test (mg/2 mL)
Carob fiber	0.031	0.076
Wheat bran	1.0	0.458
Oat bran	>1[b]	0.384
Oat bran concentrate[a]	>1[b]	0.767
5-Aminosalicylate	nd[c]	0.006
Trolox	0.094	nd

[a] Rich in β-glucan.
[b] Samples were almost inert.
[c] Not determined.

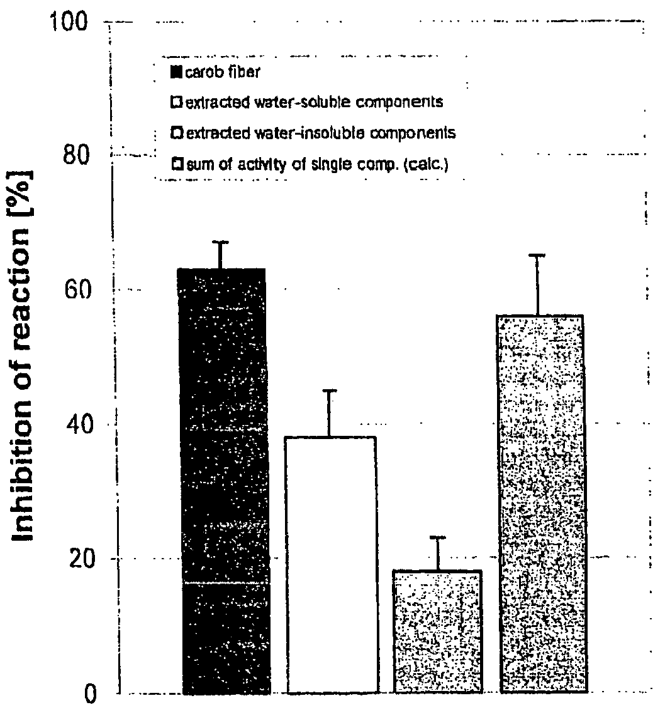

Fig. 2. Influence of carob fiber fraction on the ability to scavenge ROS in a NADH/diaphorase system.

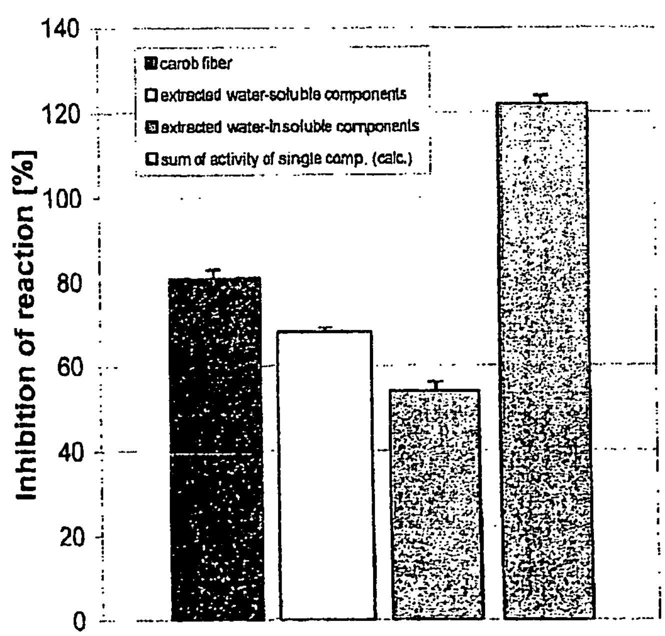

Fig. 3. Influence of carob fiber fraction on the ability to scavenge HOCl.

Carob fiber has been tested in a variety of baked goods, including breads, rolls, cakes, and cookies. In baking tests, carob fiber was substituted for part of the flour was partially, but apart from adding additional water, the original formulations were not changed in any other way. The theoretical water loss during the baking process was taken into account, so the fiber content described below is always based on the end product.

Breads and Rolls. Carob fiber can easily be incorporated into breads and rolls. In a human study, rye bread with 6% carob fiber was used to positively influence cholesterol levels. Because the response to the bread was positive, it was easier for participants in the study to follow the prescribed diet.

In a series of tests, wheat, rye, and multigrain breads and rolls were produced to evaluate the effects of adding carob fiber. It was possible to add 6% carob fiber to the three types of bread without dramatically changing the formulations, and the processability of all three doughs was improved. The dough surface was dry, and stickiness was reduced, facilitating automated industrial production. Even rye breads, which are traditionally difficult to handle because of their stickiness, were easier to process and exhibited very positive sensory characteristics. When multigrain rolls containing 3 and 6% carob fiber were produced, the doughs absorbed 2–3 and 4–6% more water based on the flour, respectively.

Other Baked Products. Addition of 3 and 6% carob fiber to muffins yielded acceptable products. The color deepened from light to dark brown with the addition of 6% carob fiber. The flavor and aroma of carob was slightly noticeable only at 6% and was regarded as positive and pleasant depending on the flavor of the muffin.

Pretreatment of carob fiber with steam resulted in a smoother mouthfeel, improved functionality, and better overall impression. Addition of carob fiber up to 6% was possible for brownies, gingerbread, cookies, and cakes; sufficient water must be added to the original formulation, however. A positive effect on texture was observed when 1.5–3% carob fiber was added. The sticky texture of the brownie dough was reduced and processability was improved by adding carob fiber, resulting in a lighter, softer end product.

Because of its chocolate-like color, carob fiber is suited to baked products containing chocolate. Depending on the amount of carob fiber in the product, the slightly bitter taste of cocoa can also be reduced. It is possible to replace 50% of the chocolate in cakes, muffins, and cookies with carob fiber without making major changes to the formulation.

Shelf-life Extension

The water absorption characteristics of fiber can be used to benefit the end product. By holding moisture, fiber can act as a humectant to enhance the softness of baked products and help extend shelf life. Carob fiber binds 3–3.6 times its weight in water (depending on the application), which helps improve product quality and reduce microbiological growth promoted by free water.

The antioxidative activity of carob fiber in food systems can also help improve product shelf life. In biscuits, for example, carob fiber showed an antioxidative effect and shelf-life extension similar to that of a tocopherol when used at 6% levels (Fig. 4). Because dietary fibers with no antioxidative activity had no comparable effect, links observed between antioxidative activity and nonspecific physicochemical interactions between the fiber components and the food matrix were dismissed.

Conclusions

Carob fiber can be used in a broad range of foods as a multifunctional ingredient with health-promoting properties. Carob fiber added to food products has been shown to help significantly reduce plasma cholesterol levels, especially LDL cholesterol, without causing an adverse reaction. Furthermore, carob fiber contains substantial amounts of insoluble and water-soluble polyphenols that exhibit antioxidant potential. Because the antioxidative capacity of carob fiber is found in both its water-soluble and insoluble fractions, its antioxidative properties may be available from the gastrointestinal tract to the blood serum and other systems in the human body.

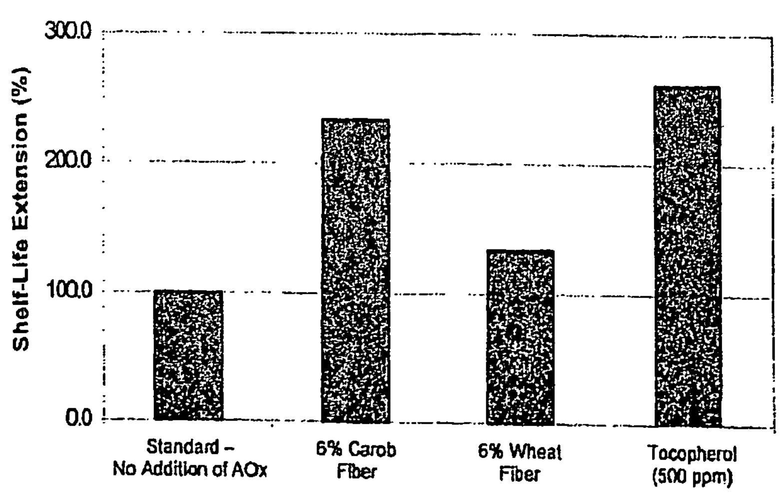

Fig. 4. Ability of added carob fiber to extend shelf life of biscuits compared with added wheat fiber or tocopherol or standard biscuits.

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